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Modelling in Waterways Engineering - Expectations and Challenges

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1. Introduction

The German Federal Waterways and Shipping Administration (WSV) is responsible for the construction, operation and maintenance of the German waterways, with inland waterways of a length of 7,350 km. The WSV is in charge for some 290 weirs, 450 lock chambers, 500 culverts, 1,600 bridges, 15 canal bridges, 11 barrages, 4 ship lifts and numerous other structures, such as groynes and riprap designed to support inland navigation.

In the expansion, operation and maintenance of federal waterways, all sectors of waterway engineering are in demand. The new construction of a lock, such as the currently planned lock Lüneburg at the Elbe side channel, requires expertise amongst others in the fields of construction engineering (construction, structural engineering, building materials, hydraulic steel construction), geotechnical engineering (subsoil, groundwater), hydraulic engineering (filling and emptying systems) and driving dynamics (entry and exit conditions). In all these areas, modelling, especially in the planning phase, is a central and indispensable method of investigation.

As waterways engineering consultant and expert, the Federal Waterways Engineering and Research Institute (BAW) supports the WSV and the Federal Ministry of Transport and Digital Infrastructure (BMVI) in the development and construction and the operation and maintenance of the waterways in Germany. In order to maintain and improve the quality of its consulting services, the BAW conducts research and development projects (R & D) in the entire spectrum of waterways engineering, including across disciplines.

2. Challenges on Federal Waterways

The major challenges facing waterway engineers today are the overaging of a great part of the hydraulic infrastructure, the trend towards larger vessels, the ongoing erosion processes in the free flowing parts of the rivers, the optimization of river training and sediment management and the potential impacts of climate change on navigation. In addition, there is a growing need to consider environmental issues, e.g. from the European Water Framework Directive. Green shipping and the topic of digitalization and automation are further major challenges.

2.1. River Engineering

Even though the numerical simulation models as a result of the continuously increasing computing power and further developments in recent years have developed into powerful tools that are indispensable for task processing, there is still a considerable need for development. For example, it is important to significantly increase the computational efficiency of multidimensional numerical methods in order to be able to carry out long-term simulations over many decades within tolerable computation times.

Processes such as the start of bed load transport, transport over a solid bed or sediment transport in the form of dunes are not yet sufficiently understood and are therefore still described using empirical approaches and thus always with limitations in terms of scope and predictive quality of the modelling. For this purpose further investigations are necessary, also to take account of three-dimensional flow effects.

It is also important to consider the grain size composition of the subsoil by means of improved multi-layer models for a reliable prediction of the bottom development. Last but not least, there is a great need to quantify the uncertainties in the model results by methods of reliability analysis in order to better assess the quality of the impact predictions of morphodynamic modelling (Kopmann and Schmidt 2010).

2.2. Ecological Connectivity

In the tasks of ecological connectivity, high-resolution three-dimensional flow modelling for the investigation of findability and passability of fish passages play a central role. Corresponding building-related modelling, to simulate pool hydraulics or the hydraulics of special structures (e.g. distribution basins), require experience in the field of turbulence modelling as well as sufficiently large computing resources. At the BAW, these three-dimensional flow modelling is nowadays a standard task. In contrast, the modelling of the highly turbulent underwater of a hydropower plant for hydraulic assessment of the entry situation (the attraction flow of the fishway in competition with the power plant outflow) remains to be a challenge. The continuous development of the modelling of these flow processes is therefore a focus of the work of the BAW (Gisen et al. 2016).

Another challenging research task in this field is also the development of numerical methods that allow to simulate fish behavior in different hydraulic environments, e.g. on the basis of an individual-based modelling (so-called agent-based models). Such a model would make it possible to evaluate a large number of different variants with comparatively little effort in the planning phase of a fishway.

2.3. Hydraulics at structures

High-resolution three-dimensional flow modelling plays a central role in the hydraulic engineering studies at structures. The hydraulic issues that arise in the process of filling a lock, for example - at what speed the lock chamber can be filled, how appropriate valve schedules must be designed, etc. - can today be reliably answered on the basis of corresponding modelling experience (Thorenz 2010). This also applies to questions about the efficiency of weir systems.

On the other hand, challenges for a numerical simulation arise in processes involving fluid-structure interaction, in the movement of solid bodies in the flow, as well as in problems involving multiphase flows. The simulation of vibration phenomena, which can occur, for example, with over- or underflowed deformable or elastically mounted bodies with high damage potential (e.g. weir closures or sealing seals), requires a coupling of flow and structural mechanics approaches.

Within the framework of an interdisciplinary research project investigating the causes, effects and remedial measures of flow-induced vibrations in hydraulic steel engineering, one of the goals is to simulate typical vibration phenomena using numerical methods.

One of the most challenging tasks is the numerical simulation of the motion of solid bodies in the flow. This concerns both the modelling of a moving ship and the modelling of ship movements when filling a lock, as well as the determination of the hydrodynamic forces acting on the ship. To successfully model ship motion with a grid-based method, it is important to explore the possibilities and limitations of adaptive or moving grids. The development of appropriate procedures is currently the subject of an R & D project in the BAW.

Air intake and ways to avoid it have always been relevant topics in hydraulic engineering. However, a physically consistent numerical simulation of air-water flows is still pending. To achieve this, intensive research efforts are still needed.

2.4. Interaction of Shipping and Waterways

The interaction of ship movement with ship-induced flow in flowing or stagnant waters, which determines the forces on the ship in laterally and vertically limited cross sections, is usually only taken into account parametrically in the dynamic modelling of inland waterway vessels. However, reliable modelling of ship movements requires determination of the forces on the underwater vessel. Therefore, modelling of ship-induced flows is a mandatory prerequisite for improving the semi-empirical calculation approaches used today for the determination of flow forces by physically based, parameter-free simulations. This will make it possible in the future to replace costly nature tests, which are only valid for one type of ship with a certain load, by simulations.

In addition to the further development of navigational model procedures, there are major challenges in the fields of “environmentally friendly shipping” and “digitalization and automation”. The BAW is conducting research on the topic "Environmentally-friendly design of traffic and infrastructure" in the BMVI expert network with regard to operational and technical optimizations for emission reduction.

With regard to digitization and automation, there is a great need to analyze the methodological prerequisites for the semi-autonomous operation of inland waterway vessels, to improve the usability of the necessary data sources and to develop concepts for automated data processing throughout the entire process chain. Intelligent assistance systems are playing a key role here, especially with regard to a modern energy and emissions management, optimization of load draught, course and driving style, as well as intelligent traffic management that optimizes traffic flow and minimizes the local accident risk from increasing traffic (Schröder 2017).

3. Outlook

Despite the progress made in recent years in the field of two- and three-dimensional flow simulation, developers and users are facing major challenges in the coming years. These not only concern the model development itself, but also the areas of pre- and post-processing, data analysis and data management. Due to the rapid development of hardware in recent years, the testing and evaluation of software adaptations to new hardware architectures is an up-to-date and challenging topic. In the future, it will be a major task to quantify the uncertainties in the input data and parametrizations in order to make statements about the reliability of the results on the basis of probability-based methods. Numerous waterway engineering problems will greatly benefit from advances in modelling, e.g. from the modelling of the fluid-structure interaction, the hybrid modelling of morphodynamic processes and the modelling of the complex interaction of ship dynamics and flow in narrow waterways.

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